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Labor productivity and energy use in a three sector model: An application to Egypt

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Abstract

This paper presents a model of a developing economy with three sectors—industry, agriculture, and energy. Industry and energy are assumed to be demand–constrained, but agriculture supply–constrained. The model highlights (a) structural transformation, through labor transfer from agriculture to industry, (b) inflation, driven by the interaction of demand and the supply constraint in agriculture, and (c) the link between energy use and labor productivity. Employing a Kaldor–Verdoorn productivity rule in industry augmented with energy intensity—energy per unit of labor—as an argument, we emphasize that labor productivity growth is driven by energy intensity rather than energy productivity growth. As a consequence, emissions reduction without North–South technology transfer and financial assistance costs growth.

1 Introduction

The defining characteristic of many developing countries is structural heterogeneity—the existence of modern production activities side by side with informal, traditional activities (Prebisch (1959); Polanyi Levitt (2005)). The fundamental policy challenge for developing countries is to provide productive employment opportunities for often still fast growing populations and to raise labor productivity. If GDP growth is strong enough, transfer of labor from low productivity to high productivity activities can support a virtuous circle of development and growth (Kaldor (1978); Ocampo (2005)). Generating employment in high productivity activities is difficult enough. It can be

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further complicated for several reasons, some of which have been raised for decades in the field of development economics.

A surge in labor productivity in industry can reduce demand for labor, and hence increase the share of workers in informal activities (Rada (2010)). Strong demand, on the other hand, leads to productivity growth *with labor transfer*. But growth of industrial employment, rural–urban migration and other global factors can lead to upward pressure on agricultural prices (Lewis (1954); Harris and Todaro (1970); Kalecki (1976)). The resulting decrease in real wages in terms of necessary agricultural goods can choke off an expansion, especially when external demand is weak or export capacities are underdeveloped (Taylor (1983)).

These issues have regained prominence in the ongoing debate on macroeconomic development policies. Despite strong growth performances, several so–called success stories show mixed employment pictures. China and India are only the two largest developing countries where jobless growth appears to have taken hold. In both countries, the share of informal sector employment in total employment is rising. High commodity prices, and specifically high prices of food and staples continue to threaten livelihoods and depress real incomes in the Global South, even if they have receded from their highs in the developed world.

Further, increasing the supply of energy and related infrastructure is of crucial importance for development prospects, but the technological, knowledge–related and cost impediments to quickly adopt high productivity designs are often considerable. High emission energy provision is then the only feasible option, and the development process will be accompanied by a rise in (fossil) energy per unit of labor (Ocampo et al. (2009)).

Growth of labor productivity can *ex–post* be decomposed into growth of energy productivity (GDP per unit of energy), and growth of energy intensity (energy per unit of labor)—and the latter has historically dominated the former (Taylor (2008)). The more heavily growth depends on rising energy intensity—as opposed to energy productivity—the more harmful emissions it creates. The increase in energy intensity stems, simply, from mechanization. The use of machinery requires more energy; the use of machinery increases labor productivity. The challenge climate change poses is to render future labor productivity increases rather the result of energy productivity increases.

In this paper, we illustrate the uphill battle especially a developing economy faces in that undertaking. Using the example of Egypt, we show first that past labor productivity growth has relied on energy intensity growth rather than energy productivity growth. Second, employing a structuralist multi–sectoral model of development with a focus on labor transfer and energy–productivity links, we show that it is likely that future (medium run) productivity growth will show the same pattern.[1] Slower (or even

[1]Economic models of climate change commonly are intertemporal full employment models of the long run á la Ramsey. Stern (2007) and Nordhaus (2008) are two important references. See Rezai et al. (2009) for a careful approach to this type of modeling. We are taking a different approach here; we do not attempt to model damage and mitigation.

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negative) growth of emissions would be possible only with either a halt to development, or with changes in technology.

We begin below with the discussion of empirical evidence on the relationship between rising energy intensity and rising labor productivity. In that section, we will as well review statistics on economic performance and structural change in Egypt. Section 3 presents the model. It includes an introductory summary; the remainder of the section might be skipped by the less technically inclined reader. Section 4 presents simulation results and analysis. Section 5 concludes.

2 Structural change and energy demand in Egypt

Sustained economic growth per capita is a fairly recent phenomenon. Over the last, say, two hundred and fifty years, the combined forces of fossil energy production and manufacturing have lead to manifold increases in living standards in large parts of the world. Here, we review this through the lens of the past few decades in Egypt.

First, we show that Egypt has not experienced a successful transition towards manufacturing. Instead, the country has relied on low–productivity employment in agriculture and services to absorb the labor force. Policy should aim to trigger a virtuous circle of dynamic structural change, which could sustain growth of labor productivity and living standards. However, second, that would require energy intensification and the accompanying fossil emissions. Indeed, we show that labor productivity growth in Egypt since 1970 was driven by energy intensity growth, not energy productivity growth. Based on these observations, we motivate an augmented Kaldor–Verdoorn productivity rule, which takes energy intensity, besides demand, as an argument.

Development and growth require structural transformation towards high productivity, high value added activities. Manufacturing, the most energy intensive sector, has the highest potential to deliver increasing returns to scale and overall productivity growth through spillovers and dynamic linkages. Especially agricultural activities are often subject to decreasing returns and therefore can present a drag on productivity growth and growth in general. Still, industrialization and structural transformation is impossible without an expansion of output and productivity in the agricultural sector. Provision of affordable foodstuffs is crucial to alleviate poverty. Further, inflation of food prices has negative effects on external competitiveness.

[**Figure 1–4 about here**]

A decomposition of GDP growth by sectors reveals that manufacturing and agriculture's contribution to growth has stagnated in recent decades. See Figure 1.[2] The

[2] Aggregate value added is calculated by summing value added across sectors, $X = \sum_{i=1}^{n} X_i$. Total differentiation of this expression with respect to time allows us to write the growth rate of value added as a weighted average of sectoral growth rates in value-added, $\hat{X} = \sum_{i=1}^{n} \theta_i \hat{X}_i$, where θ_i is each sector's share in overall value-added.

service sector's contribution to growth, on the other hand, has declined between the 1980s and 2000s despite the rise in the sector's weight in the overall economy. See Figure 2. Slow growth of labor productivity in services is one reason. That jobs in services tend to be low productivity and possibly informal is another. Since the 1970s overall economic growth has as well benefited significantly less from mining activities. The cause has to be seen in large fluctuations of oil prices, as documented by, for example, UNDP (2009). Overall, these numbers add to a pronounced slowdown in growth in the past two decades. Figures 3 and 4 further add to this picture. The services share of total employment has risen over the period considered. While the employment share of agriculture is falling, the employment share of industry is stagnant. Labor productivity, on the other hand, rose most strongly in industry, and more moderately at lower levels in services and agriculture.

Clearly, Egypt would—as would many other developing countries—benefit from a shift towards manufacturing and related activities, provided growth is strong enough to avoid labor shedding. To sustain growth and increased living standards, the share of industry in output and employment must rise.

Let us now consider the link of such growth and industrialization to energy demand. Reliable data on energy demand is available only for the period after World War II. Nevertheless, we can get an idea about its association with economic performance. Figures 5 through 7 show data on annual growth rates of labor productivity, energy productivity and energy intensity in Egypt. The straight lines are simple OLS regressions. Figure 5 shows the relationship between labor productivity growth and growth of energy intensity, or the ratio of energy per unit of labor. The slope coefficient is 0.18, meaning that an increase of energy intensity growth of one percent coincides with an increase in the growth rate of labor productivity of roughly one fifth of one percent.[3]

[Figures 5–7 about here]

Figure 6, in turn, suggests that there is no such correlation between growth of energy productivity and growth of labor productivity in Egypt. Further, since the sum of energy productivity growth and energy intensity growth is equal to labor productivity growth, there exists a direct trade–off between these two. Figure 7 shows that relationship: For a given level of labor productivity, an increase in energy intensity growth correlates (roughly) one–to–one with a decrease in energy productivity growth. These results are disheartening. The implication is that labor productivity growth rises with energy intensity at the expense of energy productivity. In other words, higher fossil emissions per worker are indeed a negative externality of economic growth. Past—and insufficient—structural change has been accompanied by energy intensification. With a given technology, emission reductions must cost growth.

Based on these observations, we now motivate an augmented Kaldor–Verdoorn

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[3] The slope of this regression for average growth rates of more than sixty developing countries between 1970–2004 is 0.45.

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relationship, in which we include the positive relationship between labor productivity and energy. We begin the exposition here with the aforementioned accounting identity, and then move on to the behavioral function. First, some notation. Let Y be real GDP, L a suitable index of total employment, and J a suitable index of aggregate energy use. Further, define labor productivity as $\xi_L = \frac{Y}{L}$, energy productivity as $\xi_J = \frac{Y}{J}$, and energy intensity as $\epsilon = \frac{J}{L}$. Obviously, $\xi_L = \xi_J \epsilon$, and log–differentiation gives

$$\hat{\xi}_L = \hat{\xi}_J + \hat{\epsilon}, \tag{2.1}$$

where a "hat" over a variable indicates the growth rate of said variable. In words, growth of labor productivity is *ex–post* identically equal to the sum of the growth rates of energy productivity and energy intensity. A rise in energy productivity means that the same amount of energy produces now a larger quantity of output. A decline in energy intensity implies that the average worker produces the same amount of output but uses less energy than before.

As put before, the challenge climate change poses is to rely on energy productivity growth $\hat{\xi}_J$ rather than energy intensity growth $\hat{\epsilon}$ to drive increases in living standards. This needs to be qualified. First, these two ratios can *improve*, i.e. $\hat{\xi}_J > 0$ and $\hat{\epsilon} < 0$ even if the absolute amount of energy use J rises. Clearly, in such a case harmful emissions increase—only in *relative* terms, emissions decrease. Second, employing renewable energy technology relaxes the constraint; green energy intensification is not the problem. However, the problem is that most developing countries are likely constrained in the implementation of knowledge–intensive green energy sources. Even China, with ample resources at hand and a fast growing market share in wind energy technology, continues to rely heavily on fossil energy sources for growth.

Indeed, with a given technology, as defined by fixed input–output coefficients, the model is best interpreted to describe the medium run—a period anywhere between five and fifteen years. Accordingly, we assume that renewable energy blueprints are not readily available or implementable, and focus on fossil, emissions–heavy sources of energy. We will return to this issue in the concluding discussion.

What does equation (2.1) mean for our model? Empirical evidence outlined above suggests that increases in energy intensity matter for labor productivity, so that we include ϵ as an explanatory variable. On the contrary, however, there appears to be no positive link between energy productivity and labor productivity. (Additionally, as discussed below in more detail, the fixed proportions technology implies that energy productivity is constant, except when trade effects exist.) Hence, we do not include ξ_J as an argument in the productivity rule. The standard Kaldor–Verdoorn rule determines labor productivity, of course, as a function of demand.

Accordingly, the equation for the level of labor productivity in industry can be written as

$$\xi_{L1} = \delta^0 Y_1^{\delta^1} \epsilon_1^{\delta^2}, \tag{2.2}$$

where the sub–index 1 denotes the sector, δ^0 is a parameter and δ^1 and δ^2 are the elasticities for demand and energy intensity, respectively.

What, in turn, does the behavioral function (2.2) mean for our model? Since $\hat{\epsilon} = \hat{J} - \hat{L}$, $\hat{L} = \hat{Y} - \hat{\xi}_L$, and $\hat{\xi}_L = \delta^1 \hat{Y} + \delta_2 \hat{\epsilon}$ (with $\hat{\delta}^0 = 0$ for brevity), growth of energy intensity can be written as

$$\hat{\epsilon} = \hat{J} - \hat{Y} + \hat{\xi}_L = \frac{\hat{J} + (\delta^1 - 1)\hat{Y}}{1 - \delta^2}. \tag{2.3}$$

If the economy is closed to trade, or insensitive to external price changes, the GDP–to–output ratio will be constant. It follows that $\hat{J} = \hat{Y}$, and equation (2.3) becomes

$$\hat{\epsilon} = \frac{\delta^1 \hat{Y}}{1 - \delta^2}, \tag{2.4}$$

which, with $0 < \delta^1, \delta^2 < 1$, implies that GDP growth necessitates energy intensification.

3 The model

This section presents the model. In two following subsections, we discuss the equations in detail. Let us begin here with a summary of key features, and a brief overview of the Social Accounting Matrix (SAM).

The model disaggregates the Egyptian economy into three sectors: (1) industry and services, (2) agriculture and (3) energy. The sectors are indexed 1, 2 and 3, respectively. For brevity, we will mostly refer to industry and services simply as industry. Agriculture includes all agricultural and husbandry activities except food processing, which is here considered part of industry. The energy sectors includes petroleum–related and electricity producing activities.

Table 1 shows the SAM.[4] The SAM conforms to standard bookkeeping rules. Rows summarize incomes, columns expenditures, and row and column sums are equal. The first three rows show total sales of the three sectors, the first three columns their costs—intermediates, factor costs, production taxes (net of subsidies), and imports.

Columns four through six summarize consumption and saving behavior of three households: a worker household W, reveicing wages from sectors 1 and 2, a capitalist household C, receiving profits from sectors 1 and 2, and an agricultural household A, recieving income from sector 2. Government, foreign and capital account present further sources of final demand, financed by the respective incomes.

[4]Our Social Accounting Matrix (SAM) is an aggregation of the SAM presented in El-Said et al. (2001), which has a base year of 1996/7. To construct the SAM El-Said et al. (2001) use data from Egypt's national accounts, government and trade accounts, an official SAM for 1991/2 as well as household data from the Egypt Integrated Household Survey conducted by International Food Policy Research Institute in 1996/7. We make some simplifying assumptions, explained as we go through the equations. See as well the appendix for further notes on the SAM.

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[Tables 1 and 2 about here]

Crucially, industry and services are structurally similar to industry and services in advanced economies. Large firms with significant market shares produce with excess capacity, enjoy pricing power, and satisfy current demand by varying their rates of utilization. Higher rates of utilization necessitate hiring. The growth rate of employment, however, is smaller than the growth rate of value added; in the short run due to labor hoarding, and in the medium run due to Kaldor–Verdoorn effects. Along these well–known lines, labor productivity growth increases with output growth. As discussed in detail above, we add energy intensity as an argument in the labor productivity rule.

Agriculture is fundamentally different. With a given technology and limited fertile land, output is pre–determined, and does not vary with changing levels of labor supply. However, labor *productivity* is endogenous, since a demand expansion in, say, industry leads to hiring there, and a reduction of surplus labor here. Further, given agricultural output, its price ensures that sectoral excess demand is zero.

Energy provision is modeled principally like industry. We assume for simplicity that there are no investment or public expenditures on energy. Otherwise, the sector's firms are assumed to be large, have significant market share, excess capacity and pricing power; hence, quantity–clearing. This structure is reasonable in the short and medium run. Conventional fossil–based energy provision might well be supply–constrained and price–clearing, but we will leave that topic for future inquiry and focus for now on the medium run linkages between industrialization, food prices, and energy demand.

In the following subsections, we set out the equations. Further below, we discuss the model's properties in detail.

3.1 Output and employment

Having broadly laid out the model's structure, we can proceed to present details. Let us begin with determination of outputs. In industry, real output X_1 is the sum of intermediate demands, consumption C_1, investment I_1, government expenditures G_1 and exports E_1:

$$X_1 = \sum_{i}^{3} a_{1i} X_i + C_1 + G_1 + I_1 + E_1. \tag{3.1}$$

Total consumption of the sector's product decomposes by sources of demand, $C_1 = C_1^W + C_1^A$, where subscripts denote the type of product, and (capitalized) superscripts the origin of demand for that product. Note the aggregation scheme: W–households earn (after–tax) wage income from industry and energy, and consume all of it; A–households earn (after–tax) wage income from agriculture and consume all of it; C–households earn (after–tax) profit income from industry and energy and save all of it.

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Analogous to equation (3.1), energy sector output is demand–determined,

$$X_3 = \sum_i^3 a_{3i} X_i + C_3^W + E_3, \tag{3.2}$$

with the difference that A–households do not consume (significant amounts of) energy, so that $C_3^A = 0$. In contrast to industry and energy, the level of agricultural output is capacity–constrained, and just proportional to inherited capital:

$$X_2 = \gamma K_2 = \bar{X}_2. \tag{3.3}$$

Value added in the three sectors is proportional to real outputs. We can write the share of domestic value added in supply as

$$\mu_j = \frac{Y_j}{X_j} = 1 - \left(\sum_i^3 a_{ij} + t_j^X + f_j e \right), \tag{3.4}$$

where t_j^X is a production tax net of subsidies, $f_j = M_j / X_j$ is the sectoral import propensity and e is the nominal exchange rate, quoted as the domestic currency price of a unit of foreign currency. It should be emphasized that μ_j is not an accounting but a behavioral relationship.[5] It mirrors the Leontief production structure for intermediate imports. Crucially, the ratio varies only with the nominal exchange rate e and f_j, if the latter is responsive to relative price changes.

Indeed, export and import demand can be responsive to price changes; in standard fashion export and import functions are

$$M_j = \phi_j^0 \rho_j^{-\phi_j} X_j \tag{3.5}$$

$$E_j = \chi_j^0 \rho_j^{\chi_j} X_j^f, \tag{3.6}$$

where eP_j^* the foreign price in domestic currency, P_j the domestic goods price, and $\rho_j = \frac{eP_j^*}{P_j}$ the sector's relative price. X_j^f represents world demand for j–sector product. As discussed below, price elasticities of import demand ϕ_j and export demand χ_j can vary substantially across sectors.

Investment and government expenditures on industry output are exogenous. Consumption is determined by a standard Linear Expenditure System (LES). See the appendix for the equations. We should note here that fixed real agricultural output implies that consumption demand for agricultural product from A–households is fixed, as well. It follows that a rise of intermediate demand for agricultural product can be satisfied only if modern households shift away from consumption of food, after minimum

[5]The degree of freedom accorded by the cost decomposition along each sector's column is used for the determination of the output price. The real ratio μ_j must therefore differ from that accounting relationship. An often used alternative to this specification is an "Armington" CES aggregate, from which one can derive optimal demand functions for domestic and imported product.

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"floor" consumption. (High levels of floor consumption can significantly constrain the system, as it might prohibit that from happening.) Profit income is the sum of profits generated in sectors 1 and 3, and their savings—the sole source of private savings—is equal to a constant fraction s_π of Y^C. Profit income is taxed at the rates t_t^C and t_e^C in the two sectors, respectively.

Finally, let us consider the labor market. Employment in industry and energy rises with demand. As rates of capacity utilization increase, labor demand increases. We define the following relationship

$$L_i = \frac{Y_i}{\xi_i} \tag{3.7}$$

for $i = 1, 3$, where ξ_i is sectoral labor productivity—assumed constant for the energy providing sector, but endogenous and pro–cyclical in industry. (See section 2, and specifically equation (2.2) for details on the determination of labor productivity in industry.) The agricultural sector 2, however, must absorb all surplus labor:

$$L_2 = L - L_1 - L_3, \tag{3.8}$$

where L is the constant labor force. An important implication is that there is no unemployment, but only disguised *under*employment in the agricultural sector.

3.2 Prices and distribution

The model features three sectoral output prices (P_1, P_2, P_3), three sectoral value added prices (Z_1, Z_2, Z_3), three nominal wage rates (w_1, w_2, w_3), and a set of two profit rates (r_1, r_3) and two corresponding sectoral profit shares (π_1, π_3).

Let us begin with output prices in sector 1 and 3. Prices are cost–determined. Defining $\nu_i = 1 - a_{ii} - t_i^X$, we can write the output price as a weighted average of all cost components—domestic intermediates, the factor cost index Z and imported inputs:

$$P_i = \sum_{j, j \neq i}^{3} \frac{a_{ji}}{\nu_i} P_j + \frac{\mu_i}{\nu_i} Z_i + \frac{f_i}{\nu_i} e P_i^*. \tag{3.9}$$

The corresponding value added prices for $i = 1, 3$ are

$$Z_i = \frac{1}{1 - \pi_i} \frac{w_i}{\xi_i}, \tag{3.10}$$

where w_i/ξ_i are sectoral nominal unit labor costs and $1/(1 - \pi_i) = 1 + \tau_i$ are sectoral mark–up factors.

The price of agricultural output responds to excess demand. Since X_2 is exogenous, P_2 clears excess demand in the sector, and thus is proportional to

$$P_2 \propto \sum_{i}^{3} a_{3i} X_i + C_3^W + C_3^A - X_2, \tag{3.11}$$

whereas the net price Z_2 clears the cost decomposition, and can be written as

$$Z_n = \frac{(1 - a_{22} - t_2^X)}{\mu_2} P_2 - \sum_{j, j\neq 2}^{3} \frac{a_{j2}}{\mu_2} P_j. \tag{3.12}$$

Further, in agriculture, the nominal wage varies to clear the income–value added identity, so that

$$w_2 = \frac{Z_2 Y_2}{L_2} = P_2 \xi_2, \tag{3.13}$$

which of course implies that the real agricultural wage grows at the rate of labor productivity growth in the sector. In summary, P_2 responds to demand; Z_2 responds net income per unit, in other words, to the excess of P_2 over costs; and w_2 responds to Z_2 and labor productivity.

Nominal wages in industry and energy are exogenous, but profit rates vary with the distribution of income and economic activity. The two sectoral profit rates are allowed to differ. Because sector 3 uses accumulated industrial output as capital, the rate of profit must be adjusted for the relative price. From the definition of the capital share, the profit rates can then be written as

$$r_1 = \pi_1 \frac{Z_1 Y_1}{P_1 K_1} \text{ and} \tag{3.14}$$

$$r_3 = \pi_3 \frac{Z_3 Y_3}{P_1 K_3}. \tag{3.15}$$

The mark–up rates τ_1 and τ_3 are exogenous, implying that the distribution of factor income in these two sectors is exogenous.

Lastly, we have to aggregate. The overall profit share π is just total profit income as a share of aggregate GDP, $P_y Y$. The GDP–deflator P_y is calculated as a Fisher–index of the three sectoral prices.[6] The real exchange rate index ρ is the ratio of the (import–)weighted average of import prices in domestic currency to P_y.

4 Simulation results and sensitivity analysis

In this section, we discuss simulation results. Three scenarios are considered. First, investment demand expansion in the industry represents a demand shock. A wage increase in the same sector represents a domestic price shock; a nominal depreciation an external price shock. To investigate sensitivity of model results with respect to key parameters, we consider three different calibrations for full model results (Table 3), and conduct more comprehensive sensitivity analysis for selected variables (Figures 8 and 9). We focus on trade price elasticities and the productivity rule in sector 1.

[6] The Fisher–index is the square root of the product of Laspeyres and Paasche indexes, with base year quantities and post–shock equilibrium quantities as weights, respectively.

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Before delving into the numbers, let us briefly consider a baseline calibration. Note that we do not claim that this is the "right" calibration, but only that it might be reasonable. Full econometric parameterization of the model could shed light on the issue. Here, we rather want to focus on the relationship between the model structure and energy use; as will be seen, the results are to a large extent independent from any specific calibration applied.

First, we assume that imports in the agricultural sector do not respond to real exchange rate changes, meaning $\phi_2 = 0$. With Egypt's reliance on food imports in mind, this seems not to be an overly restrictive assumption. Price elasticities of import and export demand for industry output are more responsive to price changes; $|-\phi_1| = \chi_1 = 0.75$. The import and export price elasticity of energy demand is lower at $|-\phi_2| = \chi_2 = 0.2$. Other behavioral parameters concern the labor productivity rule in industry and the linear expenditure system. The Kaldor–Verdoorn elasticity is, broadly in line with empirical evidence, set to $\delta_1 = 0.35$. The energy intensity elasticity, following our discussion above, is set to $\delta_2 = 0.2$. Engel elasticities of the linear expenditure system depend on budget shares of the base year SAM data and the assumed floor consumption of agricultural product. (Recall that floor consumption of sector 1 and 3 output is zero.) We assume $C_F^W/C_2^W = 0.2$, and $C_F^A/C_2^A = 0.6$, so that only one fifth of demand for "food" from W–households is invariable to changes in their real income, but three fifth from A–households.

[Table 3 about here]

To this baseline we add two further calibrations. Table 3 summarizes all of the relevant numbers. For each shock, the table shows three columns. The three columns report results for the three calibrations, shown at the bottom of the table. The three calibrations become more "complete" from (1) to (3). (3) is the baseline calibration. (1) sets labor productivity in industry as exogenous *and* makes trade in industry unresponsive to price changes. (2) "turns on" the productivity rule, but maintains trade as a fixed proportion of output. The top block of rows show key macroeconomic statistics, the bottom block focuses on the decomposition of labor productivity growth into the energy related components, equation (2.1), for industry and agriculture.

4.1 Investment shock

We can first consider the investment shock in more detail. In this scenario, real investment demand in industry(I_1) is increased by roughly six per cent—such that the increase represents one percent of GDP. Table 3 summarizes the results. Let us begin at the top left, with calibration (1).

GDP grows at a bit more than two percent. Inflation runs at a bit less than two percent, and, accordingly, the real exchange rate appreciates. The private balance $(S - I)$ relative to GDP deteriorates by 0.7 percentage points, for the obvious reason. The public balance $(T - G)$ improves by 0.2 percentage points, since the expansion provides additional revenues. The foreign balance worsens $(E-M)$ by 0.5 percentage points, because imports are proportional to output, and increase with the expansion.[7] (Exports, on the other hand, are fully exogenous, since world demand does not change, and trade is inelastic to price changes.) We can think about these results along three dimensions: The demand expansion leads to labor transfer, inflation and energy intensification. We look at each in turn, and then move across to column (2) and (3).

Structural change is set in motion; industry's employment and output shares rise. Higher demand in industry leads to growth of output in that sector, and the accompanying growth of labor demand. Labor demand can be satisfied at the conventional wage out of existing labor surplus in agriculture. Note that *aggregate* labor productivity grows at the rate of real GDP growth, since we have assumed a constant overall labor supply. Agricultural labor productivity rises (approximately) at the rate of labor transfer.

Second, inflation runs at 1.8 percent in column (1). However, it does *not* come from rising costs—wages—in industry. Inflation arises solely due to the supply constraint in the agricultural sector: Demand expansion in industry leads to higher intermediate demand and higher incomes, which must trigger a price response to balance supply and demand in agriculture. A spike of a bit more than five percent in this sector is sufficient to lead to overall inflation.[8] Fundamentally, inflation is not *conflict*–driven, but *commodity*–driven.

Third, the energy use pattern in industry does not change. Labor productivity growth in industry $\hat{\xi}_{L1}$ is zero, and so are its components, energy productivity growth $\hat{\epsilon}_1$ and energy intensity growth $\hat{\xi}_{J1}$. With price–inelastic trade and exogenous labor productivity, *output, GDP and employment grow at the same rate.* As mentioned before, agricultural productivity growth increases with energy intensity growth, due to labor transfer.

How does the energy use pattern change with endogenous productivity in industry? Column (2) shows that $\hat{\xi}_{L1}$ is now positive. On the one hand, that leads to slower labor transfer, roughly halving the productivity (and energy intensity, and the real wage) increase in agriculture. On the other hand, it is driven exclusively by energy intensity increases in industry, since with price–inelastic trade, $\hat{\mu}_1 = \hat{Y}_1 - \hat{X}_1 = 0$, and equation (2.3) reduces to equation (2.4). Now, if we additionally make trade responsive to relative price changes, energy productivity will rise, too. Column (3) shows a small increase in energy productivity, because real appreciation triggers a fall in imports, which in turn implies that $\hat{\mu}_1 = \hat{Y}_1 - \hat{X}_1 > 0$.

Lastly, note that the sign pattern on the macroeconomic variables in the upper block is the same across all three columns. But magnitudes differ. Endogenous productiv-

[7]Private and public balance are reported as *leakage less injection* $(S-I, T-G)$ and the foreign balance as *injection less leakage* $(E-M)$ because we are accustomed to think in terms of the resulting signs.

[8]To save space, we do not show results for every single variable; sectoral output prices are part of those not reported. More detailed simulation results as well as other simulations are available from the authors upon request.

ity growth in (2) and (3) limits inflation and with it real appreciation, but reduces labor transfer. Importantly, GDP growth differs: The expansion is strongest in (1), because in addition to the investment shock, A–households experience strong real wage increases, and consume more. It is weakest in (2), because the consumption increase is muted. This negative effect, in turn, is buffered in (3) by a real export increase in industry. With endogenous productivity, P_1 falls, the sector's price competitiveness improves,[9] and exports respond.

4.2 Wage and exchange rate shock

Wage and exchange rate shock are best considered together. Let us begin again with calibration (1). Nominal wage increase in industry is expansionary, and leads to considerable inflation, which in turn triggers real appreciation. Following the real income increase, private and public balance improve, as in both sectors savings rise. The foreign balance *improves*, because the terms of trade change favorably.

Nominal exchange depreciation, on the other hand, is *contractionary.* Contractionary devaluations are especially relevant in developing countries, where intermediate and capital goods imports can be relatively price inelastic, and where the real wage reduction from depreciation cuts heavily into consumption. Krugman and Taylor (1978) argued the possibility a while ago, Storm (1997) and Razmi (2007) present more recent discussions. Here, column (1) of the exchange rate simulation shows a strong GDP contraction, strong real depreciation, and *deflation.* Following the real income fall, private and public balance worsen. The foreign balances deteriorates, by about one and a half percentage points of GDP.

As above, we can dig deeper along three dimensions—labor transfer, inflation, and energy use changes—and subsequently move across the other two calibrations. First, the consumption–driven expansion following the wage shock leads to labor transfer from agriculture to industry, and the accompanying agricultural real wage rise. The trade–induced contraction following the exchange depreciation, on the other hand, leads to (reverse) labor transfer from industry to agriculture, and a steep real wage fall for A–households.

Second, the wage–led expansion triggers (commodity–)inflation as above; but the exchange–led contraction triggers deflation. The former adds to the assumed wage inflation in industry, the latter dominates the aggregate inflation measure—for negative 3.4 percent—in the exchange rate case. We can again stress the importance of the agricultural supply constraint for these results. Commodity prices are strongly pro–cyclical, as they swing with overall demand against the supply constraint. Real incomes in agriculture, furthermore, change with transfer of labor to industry.

Third, the wage change has no effect on labor productivity and its components in industry, but the exchange depreciation raises the import bill and triggers a fall in μ_1: Energy productivity falls. (It is here where the specific form of equation (3.4) becomes

[9] Overall real depreciation is driven by the price spike in agriculture.

important. μ must denote the real GDP–to–output ratio, but it cannot come from the accounting relationship, and it must entail at least the nominal exchange rate—since otherwise the nominal exchange rate would have *no* effect under price inelastic trade.) With given labor productivity growth $\hat{\xi}_{L1} = 0$, energy intensity growth must match that with the opposite sign. GDP and employment expand or contract at the same pace, and the changing GDP–to–output ratio drives $\hat{\epsilon}_1$ and $\hat{\xi}_{J1}$.

Now, using calibration (2) brings about some changes. Calibration (2) features endogenous productivity. In the wage scenario, positive productivity growth in industry limits labor transfer and with that weakens the expansion. Still, energy productivity growth is zero, because there is no trade effect on the GDP–to–output ratio. In the exchange rate scenario, the consumption–driven contraction in industry leads to *negative* labor productivity growth. In this case, the trade–induced energy productivity loss is balanced in part by reverse labor transfer, and in part by an increase in energy intensity.

Lastly, as trade is "turned on" with calibration (3), and import and export price elasticities are sufficiently large,[10] sign patterns switch: The wage increase is now contractionary, and the exchange depreciation expansionary.

Since trade elasticities have a comparatively large impact on outcomes, the next section takes up sensitivity analysis.

4.3 Sensitity analysis and summary

Which of the three sets of key parameters is "better"? We don't know. We have not done the econometrics, and do not want to argue in favor of any. We want to emphasize that *with a given technology, increases in labor productivity must be driven overwhelmingly by increases in energy intensity.*

Figure 8 and 9 underline this point. Figure 8 has four panels. For all, the horizontal axis shows the trade price elasticities in industry from zero to one. The label of each panel indicates the variable on the vertical axis, and the shock applied to the model. As such, each panel indicates the variability of a relevant variable to a changing parameter, given the shock. When drawn randomly, these experiments are often called Monte Carlo. Here, we simply increase the trade elasticities from zero to 1 in small steps, and each time subject the model to—Panel (a)—the exchange rate shock.

The result is clear, and unsurprising: There is a threshold beyond which a nominal depreciation becomes expansionary. Panel (b) complements this. Here, we consider the investment shock, which induces an output price fall in industry due to the increase in labor productivity. The higher is the trade elasticity, the more can the economy benefit. The bottom two panels illustrate the labor productivity growth decomposition. Energy productivity growth is zero, if trade is unresponsive to price changes; and increases, the stronger trade responds to price changes. Energy intensity growth,

[10] As mentioned, both import and export price elasticities are calibrated to 0.75 in industry, and 0.2 in energy. The aggregate Marshall–Lerner condition holds with the appropriately weighted sum of the elasticities.

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however, makes up the bulk of labor productivity growth, and varies fairly little with a changing elasticity.[11]

Since our augmented Kaldor–Verdoorn rule includes energy intensity as an argument, we add Figure 9. Figure 9 summarizes sensitivity of key variables to changes in the energy intensity elasticity δ_2 in equation (2.2). We vary δ_2 from zero to 0.3. Panel (a) and (b) indicate that a higher energy intensity elasticity will strengthen the expansion following a depreciation and a demand shock. Since we use here the trade elasticities of the baseline calibration (3), a higher δ_2 simply exacerbates the price *fall* in industry, and with that boosts external gains. In line with the fact that these are secondary effects, the impact is not too large.

The bottom two panels again show the labor productivity growth decomposition. Energy productivity growth is as well driven by the trade effect. The higher the intensity elasticity, the stronger is labor productivity growth, the more pronounced are relative price changes and substitution away from imports—which drive up μ_1, and accordingly ϵ. Lastly, on the right, energy intensity feeds back positively into itself. A higher elasticity drives up ξ_{L1}, which reduces L_1 and, in consequence, increases energy intensity. The "intercept" represents energy intensity resulting from traditional Kaldor–Verdoorn effects.

Crucially, as above, across all different calibrations, labor productivity growth stems overwhelmingly from energy intensity growth. Energy productivity growth, in turn, is not driven by changes in, well, "the way things are done," but by trade effects. Such trade effects can certainly last over the medium run, but are small, and arguably not a sustainable source of labor productivity growth.

In summary, the model's behavior can be explained along the lines of (1) labor transfer, (2) the agricultural supply constraint and resulting inflationary tendencies, and (3) the labor productivity growth decomposition. Certainly, we have not build a model with technological upgrading, or the possibility of green energy production. But, many developing countries do not have the relevant capabilities—making the case presented here the relevant one for multilateral negotations on emissions reductions. Below, we close with a note on that issue.

5 Conclusions

This paper presents a fairly standard model of a developing economy augmented by an energy providing sector. We analyze the links between industrialization, the agricultural supply constraint and energy use. The discussion focuses on the fact that labor productivity growth must stem from either increases in energy productivity or energy intensity. Results show that, across a number of different parameterizations, aggregate labor productivity growth is driven by increased use of energy.

[11]Energy intensity increases with a higher trade elasticity, because higher output due to higher net export leads to higher labor productivity—which in turn reduces labor requirements in industry, increasing the ratio X_1/L_1.

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The result is implicit in the model's setup, as it ultimately rests on the fixed coefficient input–output matrix. If our model—with fixed proportions technology, demand–driven output in industry and a supply constraint in agriculture—is a reasonable approximation to structural conditions in a developing economy such as Egypt, we have to conclude that *fossil emissions reduction costs growth.*

To reduce fossil emissions *and* grow, the energy input coefficient needs to be lowered, i.e. through adoption of energy efficient production methods *or* provision of green energy. If resources are available, either strategy can be pursued. In the Global South, however, where resource mobilization is an ongoing concern, that might be difficult. According to a recent UN report (UN (2009), p.VIIff), greening of growth in developing countries is possible, but a "combination of large–scale investments and active policy interventions requires strong and sustained political commitment embodied by a developmental state and, as critically, sizeable and effective multilateral support with respect to both finance and technology."

A Appendix: SAM

In this brief appendix we provide some more detail on the SAM.

Drawbacks: First, it is relatively old. Second, it does not disaggregate services and industry. Third, it does not account for informal activities. However, given the focus of this paper—a theoretical investigation of stylized links between energy use, supply constraints and development—we hope that these are acceptable.

Aggregation of households: We aggregate the ten households of the SAM in El-Said et al. (2001) into three using the source of income as a criterion. Agricultural households, for example, receive income from all factors of production—labor, capital and land—from agricultural and husbandry activities. In sectors 1 and 2, we distinguish between labor and capital incomes and assume wage–earning and profit–earning households. Wage–earning households do receive transfers of profits from businesses. For simplicitly, we abstract from these; meaning that part of profit income is suppressed in the SAM. Wage–earning households receive wage income from both industry and energy; profit–earning households receive profit income from both industry and energy.

Aggregation of consumption: To allocate consumption of the three goods to the three households, we apply household income shares in total income to the aggregate consumption demand for the product.

Multiplier matrix: Table 2 provides the output multiplier matrix. It allows in–depth analysis of forward and backward linkages of final demand changes *in a fixed–price model with demand determined output.* Since output of the agricultural sector is fixed in our model, this matrix does not apply to it. Nevertheless, the matrix provides information on the *demand* structure of the economy, so that we include it here for the sake of completeness. Industry has the largest impact on the economy through its overall multiplier of 1.65. The relevant figures for agriculture and energy are 1.42 and 1.30. As expected, own–multipliers—the diagonal elements of the matrix—are larger than one. Off–diagonal coefficients measure the strength of backward production linkages among the three sectors. Both agriculture and energy sector appear to be more dependent on industry and services through backward production linkages.

At the same time, a relatively strong backward linkage exists between sector 1 and 2. Energy, on the other hand, does not benefit much from a rise in final demand in either of the other two sectors.

B Appendix: Consumption equations

For the sake of completeness, we list the equations of the Linear Expenditure (LES) system here. Recall that only wage earners consume; we discuss profit income in a moment. W–household's disposable income is $Y_d^W = (1-\pi_1)(1-t_1^W)P_1Y_1 + (1-\pi_3)(1-t_3^W)P_3Y_3$, where $\pi_i = 1 - \frac{w_iL_i}{P_iY_i}$ for $i = 1,3$ is the sectoral capital share, and t_i^W is the (net) tax rate on sectoral wage income. W–households demand all three goods, and consume a minimum "floor" amount of agricultural product, C_F^W. We list the equations here for completeness.

$$C_1^W = c_1^W \frac{Y_d^W - P_2C_F^W}{P_1} \tag{B.1}$$

$$C_3^W = c_3^W \frac{Y_d^W - P_2C_F^W}{P_3} \tag{B.2}$$

$$C_2^W = (c_1^W + c_3^W)C_F^W + (1 - c_1^W - c_3^W)\frac{Y_d^W}{P_2}. \tag{B.3}$$

Analogously, A–households disposable income is $Y_d^A = (1-t^A)P_3Y_3$, and their floor consumption of agricultural product is C_F^A:

$$C_1^A = c_1^A \frac{Y_d^A - P_3C_F^A}{P_1} \tag{B.4}$$

$$C_3^A = c_1^A C_F^A + (1 - c_1^A)Y_d^A. \tag{B.5}$$

Profit recipients, the C–households, do not consume. Their income is $Y^C = \pi_1P_1Y_1 + \pi_3P_3Y_3$, and their savings—the sole source of private savings—is equal to a constant fraction s_π of Y^C. Profit income is taxed at the rates t_1^C and t_3^C in the two sectors, respectively.

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Tables and Figures

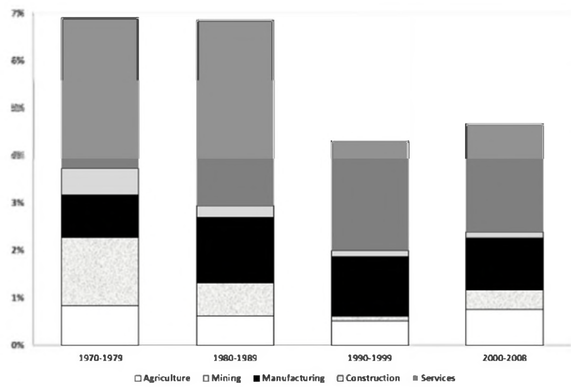

Figure 1: Sectoral contributions to aggregate output growth, Egypt 1970 – 2008. Source: UN SNA and author's calculation.

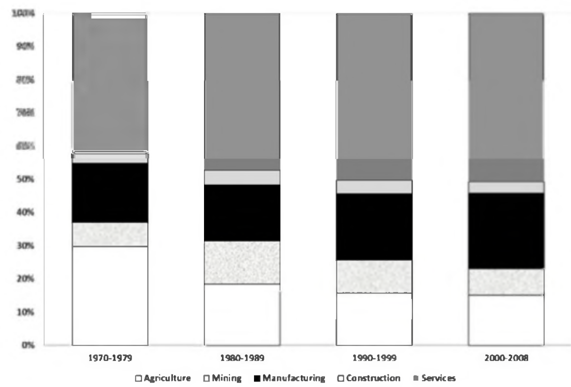

Figure 2: Sectoral output shares, Egypt 1970 – 2008. Source: UN SNA and author's calculation.

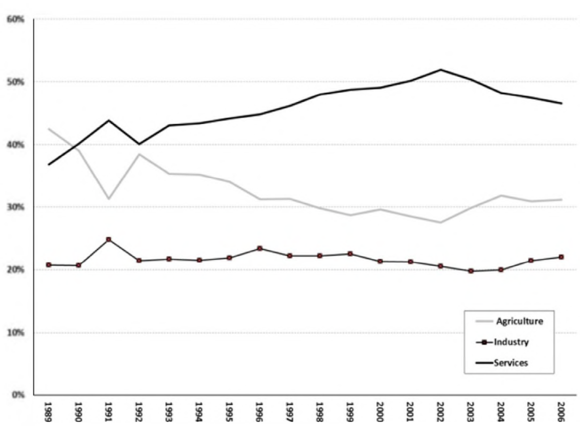

Figure 3: Sectoral employment shares, Egypt 1989 – 2006. Source: ILO Global Employment Trends (GET) and author's calculations.

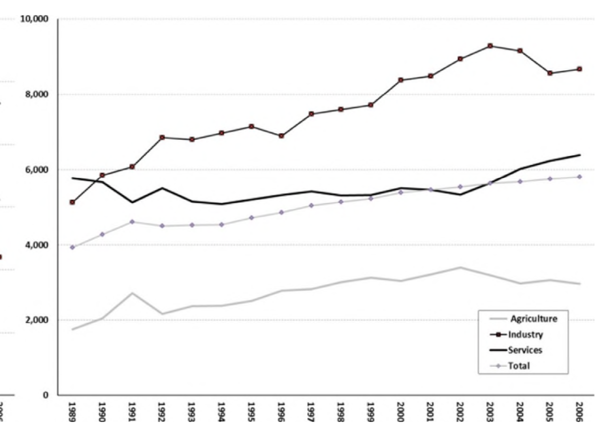

Figure 4: Sectoral productivity leves, Egypt 1989 – 2006. Source: ILO Global Employment Trends (GET) and author's calculations.

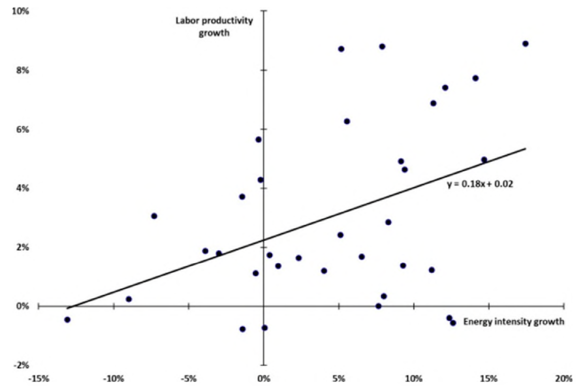

Figure 5: Growth rates of labor productivity and energy intensity. Sources: Energy: UN Energy Statistics Yearbook; GDP: UN SNA; employment: Groningen Growth and Development Center.

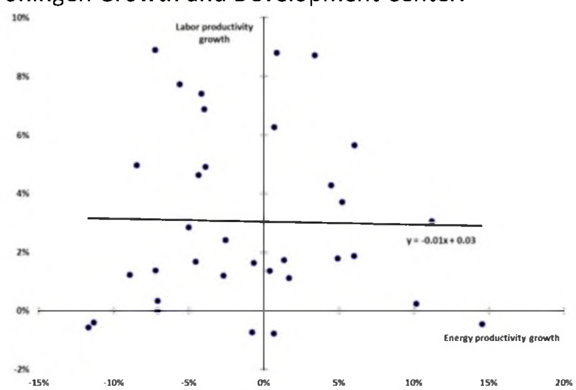

Figure 6: Growth rates of labor productivity and energy productivity. Sources: Energy: UN Energy Statistics Yearbook; GDP: UN SNA; employment: Groningen Growth and Development Center.

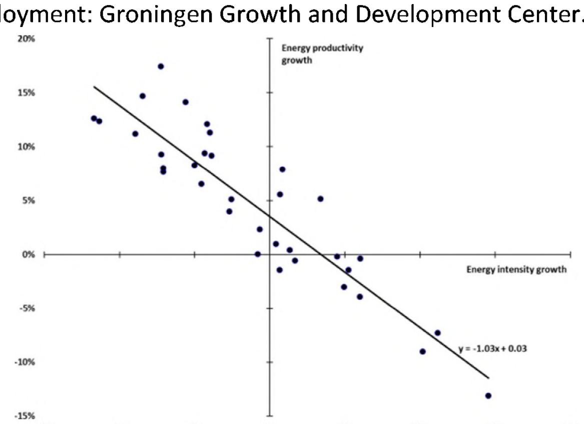

Figure 7: Growth rates of energy intensity and energy productivity. Sources: Energy: UN Energy Statistics Yearbook; GDP: UN SNA; employment: Groningen Growth and Development Center.

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	Costs			Consumption			Gov	Foreign	Inv	Sum
	1	2	3	W	C	A				
1 Industry	131.6	9.2	5.6	117.4		40.2	29.6	54.9	45.2	434
2 Agriculture	25.7	11.3	0.0	23.7		8.1				69
3 Energy	12.1	0.1	0.4	3.4				13.1		29
Wages	154.0	51.7	1.8							207
Profits	42.2		15.6							58
Government	17.7	-9.4	0.0	11.2	11.4	3.4				34
Foreign	50.5	5.9	5.7							62
Flows of funds					46.3		4.7	-5.9	-45.2	0
Sum	434	69	29	156	58	52	34	62	0	

Table 1: Social Accounting Matrix (SAM) for Egypt 1996/1997. See Section 3 and Appendix A for discussion.

	1	2	3
1 Industry	1.49	0.21	0.26
2 Agriculture	0.11	1.21	0.02
3 Energy	0.04	0.01	1.02
Multiplier	1.65	1.42	1.30

Table 2: Multiplier matrix. See appendix B for discussion.

	Demand 10% real investment			**Wage** 10% nominal wage			**Exchange rate** 10% nominal		
	1	2	3	1	2	3	1	2	3
Macroeconomic statistics									
Real GDP growth	2.2	1.8	2.0	3.3	2.8	-2.1	-5.8	-5.2	1.1
Inflation	1.8	0.5	0.5	12.6	10.5	9.3	-3.4	-0.9	0.4
Real exchange rate	-1.7	-0.5	-0.5	-11.2	-9.5	-8.5	13.9	11.0	9.6
Private balance (Δ in % pts of GDP)	-0.67	-0.72	-0.69	0.36	0.31	-0.39	-1.03	-0.92	0.12
Public balance (Δ in % pts of GDP)	0.17	0.15	0.16	0.24	0.21	-0.14	-0.48	-0.41	0.11
External balance (Δ in % pts of GDP)	-0.50	-0.57	-0.53	0.61	0.52	-0.52	-1.51	-1.32	0.24
Employment share of industry (Δ in % pts)	2.1	1.0	1.1	3.1	1.5	-1.5	-5.2	-3.1	0.7
Output share of industry (Δ in % pts)	0.5	0.4	0.4	0.6	0.5	-0.6	-1.0	-0.8	0.6
Productivity & Energy									
Industry & services									
Labor productivity growth	0.0	1.0	1.1	0.0	1.5	-0.9	0.0	-2.1	1.0
Energy productivity growth	0.0	0.0	0.1	0.0	0.0	-1.5	-2.6	-2.6	-0.6
Energy intensity growth	0.0	1.0	1.1	0.0	1.5	0.7	2.6	0.5	1.5
Agriculture									
Labor productivity growth	9.3	4.2	4.7	14.5	6.3	-5.7	-18.4	-12.2	1.6
Energy productivity growth	0.0	0.0	0.0	0.0	0.0	0.0	-1.1	-1.1	-1.1
Energy intensity growth	9.3	4.2	4.7	14.5	6.3	-5.7	-17.5	-11.2	2.8
Key parameters									
Trade price elasticities in industry	0	0	0.75						
Kaldor-Verdoorn elasticity	0	0.35	0.35						
Energy intensity elasticity	0	0.20	0.20						

Table 3: Simulation results. This table summarizes model results in response to three different shocks—a demand, a wage and an exchange rate shock—with three different sets of key parameter values each; (1), (2) and (3). All three concern industry. Calibration (1) "turns off" trade price responsiveness and labor productivity in industry; (2) "turns on" labor productivity, and (3) activates as well trade, with import and export price elasticity set to 0.75.

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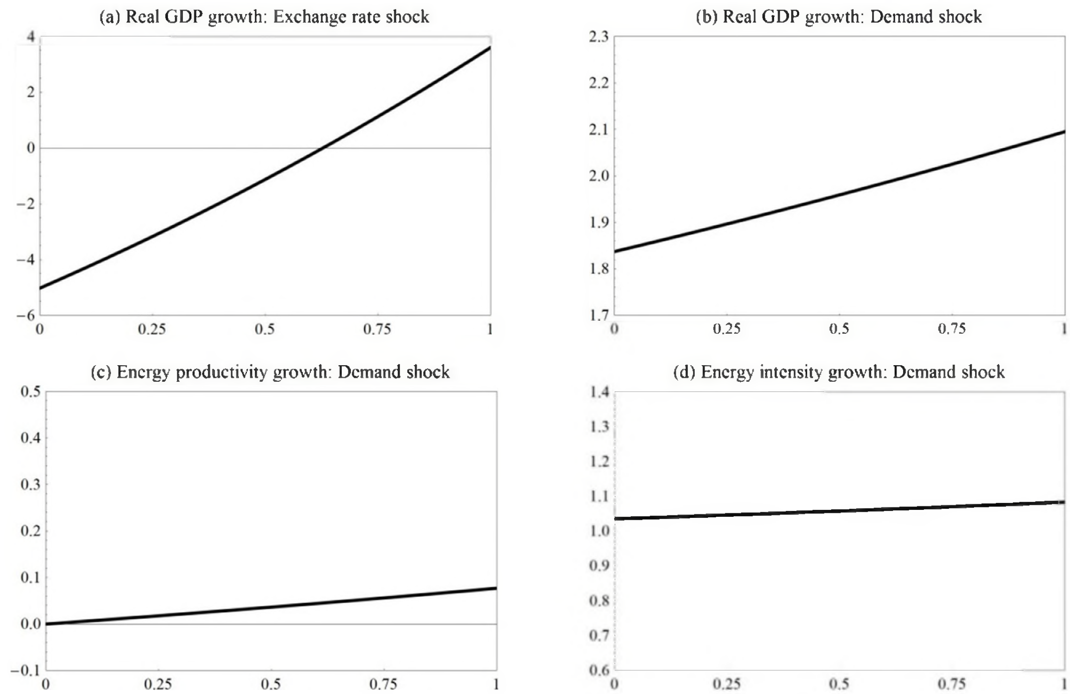

Figure 8: Sensitivity of model results to varying trade price elasticity ($\phi_1 = \chi_1$) in industry. Shocks are as in Table 3. Horizontal axes in all four panels show varying ϕ_1, χ_1 for the interval [0,1]; vertical axes growth rates in percentage points. As an example, consider Panel (a): The higher the trade elasticity, the higher is real GDP growth in response to a nominal depreciation.

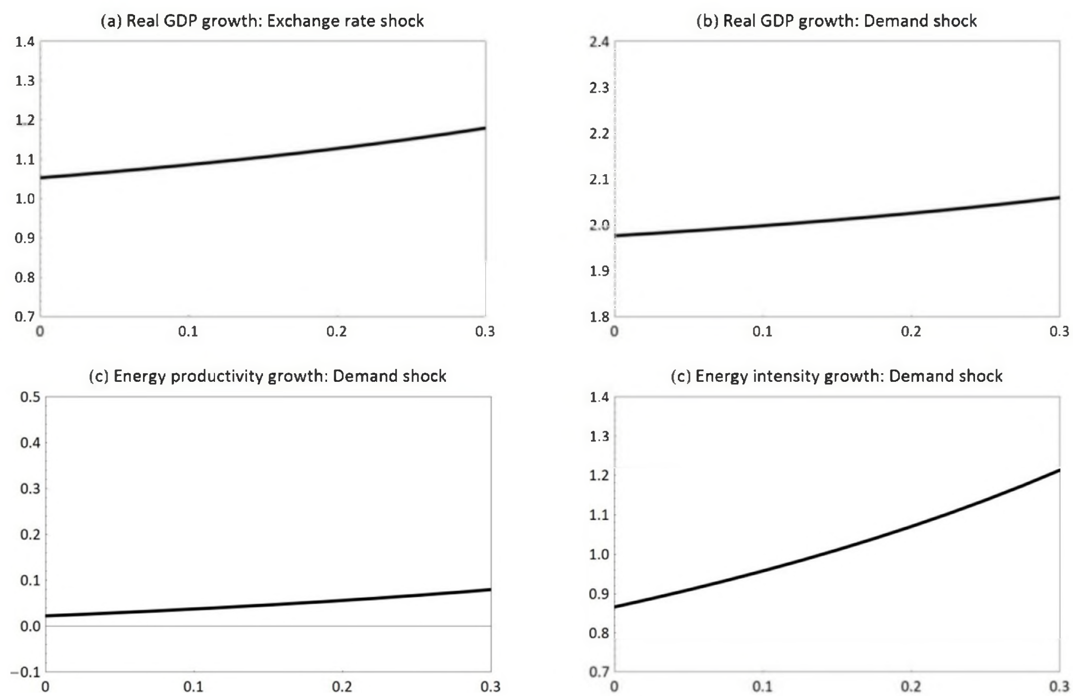

Figure 9: Sensitivity of model results to varying energy intensity elasticity δ_2 in industry. Shocks are as in Table 3. Horizontal axes in all four panels show varying δ_2 for the interval [0,0.3]; vertical axes growth rates in percentage points. As an example, consider Panel (c): The higher δ_2, the higher is $\hat{\xi}_J$ in response to a demand shock.